still feeding and without signs of pupation. During the winter and spring of 1908, the writer was engaged on other work, and compelled to neglect the notes on this borer. However, on July 9, the cage was again examined, and a single female beetle found beneath the pole. July 27 a male was taken from the cage, and another of the same sex, two days later. On August 17, another female was secured. No more adults appearing, the pole was later taken out, and split up, no larvæ or pupæ being found.

While incomplete, these records show that the life cycle of this beetle extends over a period of at least two years, and more likely three years are occupied in its various transformations.

LOCOMOTION OF CERTAIN YOUNG SCALE INSECTS

By H. J. Quayle

The object of this paper is to present a few experiments on the powers of locomotion of the Black Scale (*Saissetia oleæ* Bern.), the Red or Orange Scale (*Chrysomphalus aurantii* Mask.) and the Purple Scale (*Lepidosaphes beckii* Newm.). These three scales represent the most important insect enemies of citrus trees in southern California, and the question of how they are spread and what part their own powers of locomotion play in the matter frequently come up for discussion.

The distribution of scale insects over long distances is effected mainly through the interchange of nursery stock, and over the same general community by birds and active insects, chiefly, together with the agency of man in his usual cultural operations, while in the spread from tree to tree or to nearby trees, aside from the above factors, the power of the insects to transport themselves must be taken into consideration. The wind is another factor which may aid certain insects in distributing themselves, either by blowing them directly or with a leaf or light twig upon which they may be resting. Such insects as winged plant lice or the males of scale insects have frequently been observed to be wafted by a gentle breeze or aided in their flight through its influence. Experiments with a foot bellows showed that young black scales are not very readily dislodged from a twig, but once dislodged might be carried a short distance as they fell. Twigs having numerous active young scales had to be brought to within about six inches of the mouth of the bellows before any of the insects were dislodged. It thus requires a stronger wind than

usually blows to have any effect on the scales on the tree, but once dislodged the wind might carry them to an adjoining tree if the foliage of the different trees were in close proximity.

Rate of Travel Over Smooth Paper

In order to determine the maximum distance that young scale insects would travel under the most favorable conditions, accurate records were made of the movement of the insects over smooth paper for two-hour periods. Tracings representing their actual movements were made on large sheets of paper and will be reproduced in a later publication. Tabulation of the data is given in the accompanying table. It will be seen that temperature has a very great influence on the activity of the insects. The minimum temperature of 73.5° F. on which records were made for the black scale shows a maximum distance traveled of 81 inches with an average of 71.5 inches, while with a temperature of 90° F. the maximum distance traveled was 180 inches with an average of 151 1-3 inches. It thus appears that an active young black scale will travel more than twice as far upon a raise in temperature from 70° to 90° F.

The influence of temperature is similarly shown in the case of the red scale. At a temperature of 66° the maximum distance traveled was 41 inches, while with a temperature of 91° the maximum distance

RATE OF TRAVEL OVER SMOOTH PAPER

Black Scale (*Saissetia oleæ* Bern.)

Exp. No.	Date	Time	Temp.	Distance	Av. Distance
1	Nov. 2, 1910.....	1.45–3.45 p. m.	73.5 F.	70 in.	
1	Nov. 2, 1910.....	1.45–3.45 p. m.	73.5	62 "	
1	Nov. 2, 1910.....	1.45–3.45 p. m.	73.5	81 "	71.5 in.
2	July 5, 1910.....	2.15–4.15 p. m.	80	73 "	
2	July 5, 1910.....	2.15–4.15 p. m.	80	80 "	76.5 in.
3	Aug. 17, 1910.....	9.30–11.30 a. m.	83	103 "	
3	Aug. 17, 1910.....	9.30–11.30 a. m.	83	140 "	
3	Aug. 17, 1910.....	9.30–11.30 a. m.	83	127 "	123.33 in.
4	July 19, 1910.....	2.15–4.15 p. m.	90	108 "	
4	July 19, 1910.....	2.15–4.15 p. m.	90	166 "	
4	July 19, 1910.....	2.15–4.15 p. m.	90	180 "	151.33 in.

Red Scale (*Chrysomphalus aurantii* Mask.)

5	Dec. 6, 1909.....	2.20–4.20 p. m.	66	41 "	
5	Dec. 6, 1909.....	2.20–4.20 p. m.	66	25.5 "	
5	Dec. 6, 1909.....	2.20–4.20 p. m.	66	34 "	
5	Dec. 6, 1909.....	2.20–4.20 p. m.	66	23 "	31.12 in.
6	July 20, 1910.....	2.35–4.35 p. m.	91	111 "	111 in.

Purple Scale (*Lepidosaphes beckii* Newm.)

7	Nov. 18, 1910.....	9.20–12.20 a. m.	62	9 "	
7	Nov. 18, 1910.....	9.20–12.20 a. m.	62	21 "	
7	Nov. 18, 1910.....	9.20–12.20 a. m.	62	27.5 "	19.16 in.
8	Nov. 3, 1910.....	2.10–4.10 p. m.	68	37.75 "	
8	Nov. 3, 1910.....	2.10–4.10 p. m.	68	28 "	32.87 in.
9	July 21, 1910.....	1.20–3.20 p. m.	89	111 "	111 in.

traveled in the two-hour period was 111 inches. In most cases these experiments started off with four insects but some would be lost or destroyed, so that completed records are given for but one in some instances. But since it was more desirable to have the maximum rate of travel in each case, one record, in the case of the higher temperatures, answers the purpose. With the purple scale the maximum distance traveled was 37.95 inches when the temperature was 68° and a total of 111 or more than three times the distance when the temperature was 89°.

Taking the maximum life of the active larva of each of these scales at 4 days, which seems from our experiments to be about correct, the possible maximum distance traveled during the period may be calculated. For the black scale the maximum rate of crawling for a two-hour period is 15 feet. If it continued at this rate without stopping for 4 days it would travel a total of 720 feet, but this is never actually done under natural conditions. In the first place it would never have as smooth a surface as paper to crawl over, and again it is not at all likely that such a rate of speed would be maintained constantly. On the same basis of calculation the red and purple scales would each travel a maximum distance during their active period of 444 feet. These scales almost invariably settle within one or two days after emerging, but in the absence of food they might continue to be active for 4 days. The purple and red scales travel at about the same rate for both the minimum and maximum tempera-

tures, as may be seen from the table. It was thought that the purple scale young being much larger than the red would travel faster. The young purple scale has very short legs in relation to the size of the body, these scarcely showing beyond the margins and this probably accounts for its slow and rather awkward movements. The black scale, on the other hand, is a much better traveler but, contrary to what was expected, the partly grown scale when it loosened its hold after becoming fixed, could not cover the distance traveled by those just emerged from beneath the parent.

In these experiments little difficulty was met with in keeping the insects within the limits of a sheet of paper. They would almost invariably travel toward the light, so that when one margin of the sheet was reached it was turned around so that the opposite margin was nearest the light and the scales would soon turn about and go in the opposite direction. From these observations and experiments where the light was regulated it is concluded that these young scale insects are positively phototropic.

Travel Over Sand and Orchard Soil

In the experiments on the rate of travel over sand and ordinary orchard soil, the material was placed in saucers, plates and large sheets of black paper. A narrow strip of tree tangle-foot was placed around the plate or paper a little beyond the soil to capture the insects as they crossed over. Galvanized iron cylinders were also sunk in the soil in the field and a strip of tanglefoot placed on this a few inches above the surface. These cylinders were about 10 inches high and varied in diameter from 1 to 4 feet. These were later discarded for large sheets on which the soil was placed, or circles of paper with the inside margins covered, thus leaving a strip around the outer margins of the soil area where the scales could be more closely examined upon making their way from the center. In the following experiments the details were largely carried out by E. W. Rust.

Black Scale.—Temperature 85° F. About 50 active young just taken from under the adult were liberated in a plot of sand 6 inches in diameter. After one-half hour 5 had reached the outer margin and in three-fourths of an hour about half of the insects had reached the paper. Distance 3 inches.

Temperature 84°. Several hundred active young were placed in the center of sand in a dish at 3.30 p. m. At 3.55 one reached the edge of the dish; at 4 another; at 4.02 two more; while five more reached the edge by 4.20 and ten more by 4.30. By 5 dozens had reached

the edge of the plate. Distance traveled 4 inches. A similar experiment with ordinary orchard soil gave similar results.

Temperature 84°. A plot of orchard soil one foot square was enclosed with paper and several hundred active young liberated. When the experiment was begun the morning was foggy. In 55 minutes three reached the paper, a distance of 6 inches. By this time the sun was shining and the temperature had arisen to 96°. At a temperature of 102° all the scales died.

Temperature 85°. Four hundred or five hundred young were liberated in the center of an area of soil 2 feet square at 10.15 a. m. By 12.30 p. m. about 20 reached the margin; by 1 p. m. nearly 50, and at 5 p. m. about 100. Distance traveled 1 foot. Similar experiments showed that with a 2-foot strip of soil to cross, the first insects reached the margin in approximately 2 hours. Where the width of soil was 4 feet, out of several hundred liberated only a very few succeeded in crossing it during the same day.

Experiments relating to the effect of high temperatures on young black scales showed that it is an important factor in the causes of death. Several hundred young black scales were liberated on white cardboard in the sun with a temperature of 94° to 100°; at the end of two hours they were unharmed by the heat. A similar experiment is recorded with a temperature of 106° to 110°. At 106 the scales were lively, but as the temperatures increased they moved more slowly, and at 110 almost all movement ceased, although a 2 hours' exposure did not kill them.

Several hundred just emerged black scales liberated on soil with a temperature of 108° to 110° were active for about 1 hour, but at the end of that period some were dead and at the end of 1½ hours nearly all had been killed. A check lot in the shade were not affected. A large number of young placed upon a board with a temperature of 118°, all died in 5 minutes. Scales exposed in sun on soil where temperature was 119° to 122° died within 15 minutes. Under similar conditions with temperature of 130° death resulted in 5 minutes. A check lot in the shade were not affected.

Red Scale.—Fifteen active young picked from orange were liberated in sand with a radius of 1 inch. Two had radii of 2½ inches, and 2 more measured 3 inches in radius. None crossed the soil, even in the narrowest strip of sand. One particular insect was watched closely for ½ hour and in that time traveled but a small fraction of an inch. Another experiment showed that 1 scale out of 20 liberated crossed a 2½-inch strip in 18 hours. This was repeated the following day when none crossed over the soil. Twenty were liberated in the center of a 2-inch radius of soil and none reached the edge in 3 hours.

This was repeated twice and even on the following day none succeeded in crossing the soil.

Purple Scale.—At 9 a. m., September 17, with a temperature of 86°, 25 young purple scales were placed unharmed in the center of an area of sand having a 5-inch radius. None of these reached the edge during the same day nor the day following. A similar experiment resulted negatively. A third similar to the others was started at 9.45 and out of 25 liberated one reached the margin at 3.30 (5 3-4 hours). This is the only one that succeeded in crossing a 5-inch strip of sand. The following records were made on a 3-inch radius of sand:

9–20–10 T. 93° 20 liberated at 1.30 p. m. No results.
9–21–10 T. 82° 20 liberated at 9.45 a. m., 2 out at 12.30 p. m.
9–22–10 T. 65° 10 liberated at 9.30 a. m., 2 out at 1 p. m.
No more emerged by 5 p. m. or during next forenoon.

The experiments recorded here represent but a few of the total number made, but they will serve to show how they average. In the case of the black scale it was shown that about 4 feet of ordinary orchard soil is about the limit that will be traversed by the active young. Under favorable conditions they might, therefore, through their own powers of locomotion make their way from one citrus tree to another or to a second or third tree away. But the number thus traveling would be exceedingly small as compared with the total. These records were made on soil with an ordinary mulch. Tests were made on their powers of traveling over compact soil and they invariably showed very much greater progress. A compacted irrigation furrow enabled even the young red scale to travel two or three feet, while in a loose mulch this scale makes practically no progress. The young red scale in attempting to ascend a small particle of earth falls back again and this is repeated time after time. The same is almost as true for the young purple scale. Where there is a fine mulch, therefore, the chances of the young red or purple scale reaching an adjoining tree is practically negligible.